POLITECNICO DI TORINO
Repository ISTITUZIONALE

Lightning radiation field due to channel tortuosity and branching

Original
Lightning radiation field due to channel tortuosity and branching / Vecchi G.; Zich R.E.; Canavero F.G.. - STAMPA. - (1997), pp. 496-499. ((Intervento presentato al convegno 1997 International Symposium on Electromagnetic Compatibility tenutosi a Bejing (China) nel May 21-23.

Availability:
This version is available at: 11583/2499835 since:

Publisher:
Piscataway, N.J. : IEEE

Published
DOI:10.1109/ELMAGC.1997.617197

Terms of use:
openAccess

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

04 August 2020

LIGHTNING RADIATION FIELD DUE TO CHANNEL TORTUOSITY AND BRANCHING

G. Vecchi, R.E. Zich and F.C. Canavero

Politecnico di Torino, Dip. di Elettronica, E-mail: Zich@polito.it
Corso Duca degli Abruzzi 24, I-10129 Torino, Italy

Abstract — **The effect of lightning channel branching on the temporal waveform of the radiated fields of the return stroke is modeled. The effect of branching is isolated, and compared to the effect of tortuosity of an unbranched channel.**

Introduction

The "fine structure" of the temporal waveforms observed in experimental measurements of the electromagnetic field radiated by lightning discharge entails both "macroscopic", almost-isolated irregularities, as well as noise-like jagged high-frequency components. The "macroscopic" part in some cases may be attributed to reflections, from ground or other grounding structures, while the high-frequency irregularities have been in the past years recognized to be related to the irregularities of the discharge channel [1].

In that paper the analysis was carried out for a three-dimensionally tortuous channel, constituted by straight segments, as detailed and justified therein, and the focus was on the effect of channel tortuosity on the high-frequency part of the radiation field. The effect of channel branching was not considered: preliminary results on this subject have been presented in [3]. Here, we will extend that analysis of the fine structure of the field radiated by a lightning return stroke on a tortuous, lossy, and branched discharge channel; in particular, we will investigate the effect of all the branchings *alone*, i.e. excluding the contributions to the field that arise from the abrupt change of direction of the channel, that instead constitute the tortuosity contribution to the fine structure of the field.

The model

For the geometrical modeling of the branched channel, we have employed a stepped-leader algorithm for the description of channel formation as an intrinsically two-timescale transient phenomenon, with fast advancement of the channel and almost-stationary conditions between two subsequent steps. At each step of the algorithm, the direction of a new length of channel and the probability of branch formation depend on the local (electric) field. This latter is in turn obtained via the solution of the Laplace equation with boundary conditions that include the already-present part of the channel. A typical output of this (computer intensive) numerical procedure is a tree-like branched channel that reveals right-angle turns and branching that are a consequence of the finite-differences scheme employed in the discretization of the Laplace equation. Therefore, for the sake of radiation analysis, and an "angular smoothing" will be performed on the channel, consisting in averaging two or more subsequent points.

In the following, the part of the channel that connects the cloud to ground directly will be called "main channel"; the branches can be hierarchically ordered in terms of their origin: primary branches will depart from the main channel, secondary branches will depart from primary, and so forth.

The current on the channel is obtained using an adaptation of the so-called modified transmission line (MTL) approximation described in [2]; the

0-7803-3608-9

reasons for this choice and its limitations are the same as in [2]. This model can be shown to be a high-frequency, early-time (with respect to the wavefront) approximation of the response of a (linear) lossy transmission line (TL), that accounts for the pulse damping along the propagation with a frequency-independent altitude attenuation factor. For the sake of clarity, we note that what we term "channel losses", i.e. the attenuation of the current pulse strength along its propagation along the channel, is sometimes termed differently in the literature, often making reference to the mechanism of charge removal (e.g. [2]). Using the TL model, we prefer the term "losses", since in that model (resistive) losses are the responsible of pulse attenuation.

In our model, each segment of the main channel, and each branch, is considered as a transmission line. The current pulse at the channel base is $i_0(t)$; a vast literature exists about the shape of this pulse (see e.g. [2] and references therein). Here, for the sake of simplicity, we employ a simple double-exponential pulse

$$i_0(t) = I_0[e^{-t/T_d} - e^{-t/T_r}]. \qquad (1)$$

It is known that this approximation fails to correctly reproduce the initial time derivative, and the late time decay, and we will keep this in mind in the analysis of our results; however, for the analysis of the fine structure this is not a relevant loss of accuracy.

The return stroke is assumed to propagate undistorted from ground to the first branch point along the main channel, with constant speed v, regardless of the "kinks", starting at ground level, $z = 0$, at $t = 0$; the usual value of $v = c/3$ is used throughout (The effect of altitude-varying speed has been considered in [1]). The shape of the current pulse remains unchanged along the channel, but in order to account for channel losses the an altitude-dependent attenuation is included (MTL model), so that the current incident on the first branch point is

$$i_1^+(t) = i_0(t - L_1/v)\exp(-L_1/L_c) \qquad (2)$$

where L_1 is the length of the channel from ground to the first branching point, and L_c is the damping length.

At the branching number 1, the current partitions into a reflected pulse i_1^-, that travels downward, a transmitted pulse on the main channel, i_2^+, and a transmitted pulse on the branch $i_{1,0}^+$; the partition coefficient follow the usual transmission line rules, assuming that the main channel and branch are seen from the branch point 1 as the characteristic impedance of the related transmission lines. This assumption is exact for a dispersionless TL up the arrival of reflected terms, that can be taken into account without any difficulty other than a clumsy bookkeeping, and is consistent with the MTL approximation.

Note that this mechanism amounts to a change of the shape of the total current along the (branched) channel, because of the presence of reflected, countertraveling pulses.

The procedure then follows the one outlined above in an iterative manner: the transmitted pulse i_2^+ on the main channel becomes now the one incident upon the branch point 2, and so forth. Likewise, the transmitted pulse on the primary branch branch generates reflected and transmitted pulses at the first branching into two subsequent secondary channels, at a branch point that we can label (1,1). By consistently tracking all these traveling contributions one can construct the complete MTL approximation of the current on the branched channel.

As to the choice of the characteristic impedances of each channel segment, we note that it is a classic result that a thin wire antenna is best approximated by a biconical TL. Therefore we propose here the model of slanted biconical transmission lines, in which the impedance can be found in a classic manner.

However, this choice leads to characteristic impedances that are numerically similar for the main channel and branches, leading to current partition with consistent current transmission on the branches, that do not seem to conform to the optical observations. Therefore, we will also consider a more heuristic model, in which of the characteristic impedance of a branch is considerably higher than that of the main channel.

The return stroke channel is modeled as piecewise straight; The ground is assumed flat and perfectly conducting: at ground level the vertical component of the electric field will be twice as much its free-space counterpart. Since we want to focus on the branching effect, we do not consider radiation from "kinks" not connected to a branch point. Therefore, we generate a simplified channel by connecting only the branch points.

In order to highlight the effect of branching on radiation, selection criteria can be employed for the simplification of the channel, basing on the retention of branches up to a specified hierarchical order.

Extending the model currently employed in the literature for the analysis of tortuous channels (as summarized in [1]), we on each segment we consider all the current components detailed above, that include transmitted and reflected contributions. Note that the reflected contribution is equivalent to a counterpropagating pulse, and the classic results from a straight channel, summarized in [1], can be employed directly.

For each segment, and each traveling component (upward/downward) with the Fraunhofer (far-field) assumption, and the assumption that the distance r_i between the observer to the center of the $i-$th segment is $r_i \gg \lambda$ over the entire band of interest, the vertical electric field is the sum of two contributions originating at the two ends of the segments; each contribution to the field is a replica of the current waveform at the "input" node, whose amplitude is a function of the direction with respect to the observer, and of the local pulse strength. This latter is obtained via the attenuation, transmission and/or reflection mechanisms outlined above.

Results

In this prototype calculations, we have considered the following parameters: $T_r = 5 * 10^{-7}\,\mathrm{s}$, $T_f = 3 * 10^{-5}\,\mathrm{s}$, height of the channel ground-to-cloud $h_c = 1\,\mathrm{km}$, and the total length of the main channel turns out to be $L_c = 1.2131\,\mathrm{km}$. Fig. 1, 2, 3, 4 show some typical results.

Because the characteristic impedances are not very sensitive to the geometry, each branch point sees a substantial reduction of impedance (because the two outgoing segments are shunt connected), and there is a sensible reflection from the branch points. In order to be consistent, the reflections are to be correctl[illegible]dered, since they play an important role in [illegible] model, as can be understood from Fig. 1, 2, 3, 4.

Because of the finite number of branches in the reduced model the high-frequency irregularity of fine structure is not extensively present throughout the pulse duration.

As described above two different models of the characteristic impedances of the branched channels have been considered.

In Fig. 1, 2 all the channel elements have been modeled with the slanted biconical model (SBM) for the TL impedances. In Fig. 1 four different curves have been reported in order to identify the action of the different phenomena contributing to the total radiated field: the label "*straight*" channel refers to the result obtained without considering the effects of branching and tortuosity. "*only main ch. tortuosity*" means that the branches have not been considered, but the main channel tortuosity has b[illegible]stly, the effect of ground (back) reflection o[illegible]mplete branched channel is considered, th[illegible] line including it and the dashed one not.

The results in Fig. 2 refer to the case in which the radiation contribution due to the main channel "kinks" (abrupt change of directon) have not been considered, and therefore reports the effect of branchings alone.

In order to try to fit optical observation an *heuristic* model for the channel impedances has been introduced with all main channel impedances set to 400Ω, and all branches set to 4000Ω. Fig. 3 and 4 report the same kind of results of Fig. 1, 2, with and without channel tortuosity.

In particular, branches generate a substantive change with respect to unbranched tortuous channel if branch impedance is comparable to main channel's one (SBM model). On the contrary, a modest change in the fine structure may be noticed if the branch impedance is much higher than the main channel's (*heuristic* model).

It may be noticed (see Fig. 2, 4) that branching provides a fine structure also *neglecting* kink radiation.

A marked reflection is however observed in all the considered cases from the first branch point, and reflection from ground and from the secondary branch points seem to play also a significant role in establishing the fine structure of the field within the framework of this model.

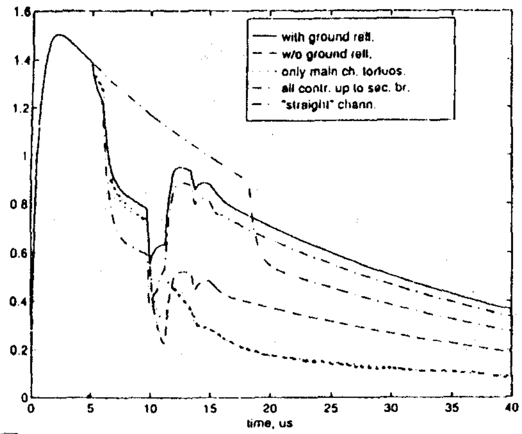

Figure 1: *Vertical electric field radiated by the considered channel. Main channel tortuosity plus branch effects. Slanted Biconical Line Impedance Model (SBM)*

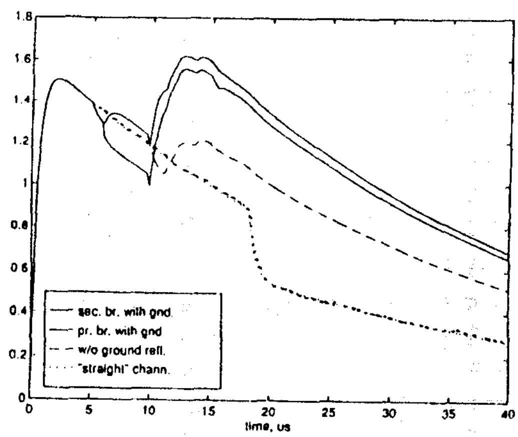

Figure 2: *Vertical electric field radiated by the considered channel. Only branch reflection and transmission effects. SBM Impedance Model.*

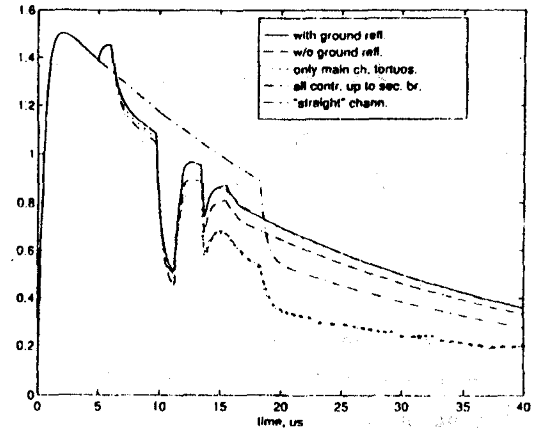

Figure 3: *Vertical electric field radiated by the considered channel. Main channel tortuosity plus branch effects. Heuristic Impedance Model.*

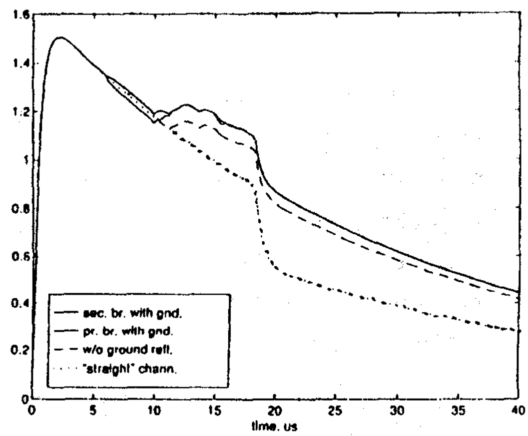

Figure 4: *Vertical electric field radiated by the considered channel. Only branch reflection and transmission effects. Heuristic Impedance Model.*

References

[1] Vecchi, G., D.Labate, F.Canavero: "Fractal approach to lightning radiation on a tortuous channel", *Radio Science* vol. 29, No. 4, pp. 691-704, July-August 1994.

[2] Nucci, C.A., G. Diendorfer, M.A. Uman, F. Rachidi, M. Ianoz, and C. Mazzetti, "Lightning return stroke current models with specified channel-base current: A review and comparison", *J. Geophys. Res.*, *95*, 20,395-20,408, 1990.

[3] G. Vecchi, R.E. Zich and F.C. Canavero, A study of the effect of channel branching on lightning radiation, *Intl. Zurich Symposium on EMC 1997*, Zurich (CH), Feb. 1997.